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ODOR AND ODOROUS CHEMICAL EMISSIONS FROM ANIMAL BUILDINGS: PART 2. ODOR EMISSIONS

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ABSTRACT. *This study was an add-on project to the National Air Emissions Monitoring Study (NAEMS) and focused on comprehensive measurement of odor emissions considering variations in seasons, animal types, and olfactometry laboratories. Odor emissions from four of 14 NAEMS sites with nine barns/rooms (two dairy barns at the WI5B and IN5B sites, two pig finishing rooms at IN3B, and two sow gestation barns and a farrowing room at the IA4B site) were measured during four 13-week cycles. Odor emissions were reported per barn area (OU h^{-1} m^{-2}), head (OU h^{-1} $head^{-1}$), and animal unit (OU h^{-1} AU^{-1}). The highest overall odor emission rates were measured in summer (1.2×10^5 OU h^{-1} m^{-2}, 3.5×10^5 OU h^{-1} $head^{-1}$, and 6.2×10^5 OU h^{-1} AU^{-1}), and the lowest rates were measured in winter (2.5×10^4 OU h^{-1} m^{-2}, 9.1×10^4 OU h^{-1} $head^{-1}$, and 1.5×10^5 OU h^{-1} AU^{-1}). The highest ambient odor concentrations and barn odor emissions were measured from the sow gestation barns of the IA4B site, which had unusually high H_2S concentrations. The most intense odor and the least pleasant odor were also measured at this site. The overall odor emission rates of the pig finishing rooms at IN3B were lower than the emission rates of the IA4B sow gestation barns. The lowest overall barn odor emission rates were measured at the IN5B dairy barns. However, the lowest ambient odor concentrations were measured at the ventilation inlets of the WI5B dairy barns.*

Keywords. *Dairy, Hedonic tone, Intensity, Odor emission, Seasonal changes, Swine.*

There has been growing concern over odor emissions from livestock production sites because of their adverse effects on livestock producers and nearby communities (Jacobson et al., 2008; Parker, 2008; Ni et al., 2009). In response to the growing concerns, local and state regulatory agencies have begun to enact new odor standards (Jacobson et al., 2008). However, the existing scientific research data are insufficient to develop appropriate standards, policies, and recommendations to control livestock odors (Guo et al., 2006; Blanes-Vidal et al., 2009; Aneja et al., 2009).

Triangular forced-choice olfactometry is a standard method (CEN, 2003; ASTM, 2001) used to quantify odor emissions from livestock buildings (Parker et al., 2005; Guo et al., 2006; Bunton et al., 2007; Parker, 2008; Jacobson et al., 2008). The use of panelists has been considered for odor quantification because the human nose can often detect odors below the detection levels of electronic odor sensors (Parker, 2008). In addition, unlike analytical techniques (e.g., gas chromatography-mass spectrometry-olfactometer), it is possible to analyze the complete sample so that the contribution of each odorous compound in the sample is included in the analysis (Jacobson et al., 2008). There are typically three parameters used to quantify odor. One of the most commonly used parameters is odor concentration (detection threshold). Most research reports odor concentration as odor units per cubic meter (OU m^{-3}) (Jacobson et al., 2008). The other commonly used parameters are hedonic tone (offensiveness) and intensity (strength) of the odor (Parker et al., 2005; Nicell, 2009; *ASABE Standards*, 2012; VDI, 1992). These two parameters are important when changes in quality rather than only quantity of the odor occurs (Qu et al., 2010).

In several studies, odor emissions from livestock production sites were measured. In each study and among different studies, large variations in odor concentrations and emission rates were observed, since there is no standard method to calculate and report odor emission rates (Casey et al., 2006; Guo et al., 2006; Sheffield et al., 2007; Yu et al., 2010). Comparing emissions from different studies is challenging, since emissions are reported in different ways, including per animal unit (AU), animal live weight, and animal space. In addition, the definition of animal space is not standardized (Casey et al., 2006), and data collection

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periods vary widely. In some cases, the original data are converted from per hour to per day or from per day to per year for comparison purposes. Conversions from hourly to daily or from daily to yearly average emissions may be misleading, since emission rates may vary widely during the day and year depending on numerous factors, such as temperature and humidity (Casey et al., 2006; Guo et al., 2006). Odor emissions can also vary depending on animal type, manure handling, feed, and bedding/floor material (Guo et al., 2007; Sheffield et al., 2007; Lee and Zhang, 2008; Yu et al., 2010).

In this study, odor emissions from four sites with nine barns/rooms (two freestall dairy barns at site WI5B in Wisconsin, two freestall dairy barns at site IN5B in Indiana, two swine finishing rooms at site IN3B in Indiana, and two sow gestation barns and one farrowing room at site IA4B in Iowa) during four seasons were measured. The objective of the study was to measure odor emission rates of four of 14 NAEMS (National Air Emissions Monitoring Study) sites using common protocols and standardized olfactometry. This study was a comprehensive odor measurement study that considered variations in seasons, animal types, sites, and olfactometry laboratories. Odor emission rates of the sites were calculated in three units (OU h^{-1} m^{-2}, OU h^{-1} $head^{-1}$, and OU h^{-1} AU^{-1}) to provide a complete set of data for odor modeling studies.

This article is part 2 of a six-article series presenting results from an NRI-funded project. In part 1, the overall project description and overview with comparisons between olfactometry labs were presented (Bereznicki et al., 2012). This article (part 2) focuses on odor emissions, hedonic tone, and odor intensity measured using standard methods and olfactometry. Part 3 deals with volatile organic compound (VOC) emissions measured with a gas chromatography-mass spectrometry-olfactometry (GC-MS-O) (Cai et al., 2012). In part 4, the correlations between the sensory (olfactometry) and chemical measurements are reported (Akdeniz et al., 2012), and part 5 deals with correlations between GC-MS-O sensory data and chemical measurements (Zhang et al., 2012). Finally, part 6 further assesses the results of the study using the relatively new "odor activity value" parameter (Parker et al., 2012).

Materials and Methods

Sample Collection

Odor samples were collected every other week from two freestall dairy sites (two barns at WI5B and two barns at IN5B) and two swine sites (two swine finishing barns at IN3B and two sow gestation barns and one farrowing barn at IA4B). Barns 1 and 2 at IN3B correspond to two rooms in the same four-room pig finishing barn (quad) and barn 3 at IA4B corresponded to one room in a 16-room farrowing building. Sampling continued 52 weeks over a span of 17 months (November 2007 to May 2009). Eight odor samples were collected from the ventilation inlet (ambient) and the primary exhaust fan (outlet) location of each barn through a positive-pressure bleed valve of a gas sampling system (GSS) (Ni et al., 2009). At sites WI5B, IN5B, and IN3B, there were duplicate ambient and triplicate outlet samples per barn (two barn inlet air and six barn exhaust air samples). At IA4B, there were duplicate inlet and outlet samples per barn (two barn inlet air and six barn exhaust air samples). Three different sampling regimes were applied during the study (Bereznicki et al., 2012), and the total sampling time was 1 h. Air samples were collected inside 0.05 mm thick 10 L Tedlar bags with polypropylene fittings during day time between 9:00 a.m. and 3:00 p.m. The Tedlar bags were prepared by West Texas A&M and Iowa State University olfactometry laboratories. Bags were flushed with zero air before sampling and used only once.

The 52-week sampling period consisted of four 13-week rounds. Every 13-week round concluded with an interlaboratory comparison (IC). For the interlaboratory comparisons, six inlet and 18 outlet air samples were collected from one site (WI5B, IN5B, IN3B, and IA4B in rounds 1 to 4, respectively) and analyzed by all three laboratories (eight samples per lab). More information about the sites, odor sample collection, and interlaboratory comparison is available in part 1 (Bereznicki et al., 2012).

Sample and Data Analysis

Odor samples were analyzed within 30 h of collection by a dynamic triangular forced-choice olfactometer (AC′SCENT International Olfactometer, St. Croix Sensory, Inc., Minn.) to determine the detection threshold (odor concentration), intensity, and hedonic tone. Samples were analyzed at the University of Minnesota, Iowa State University, and Purdue University olfactometry laboratories using the same standards and procedures.

Detection Threshold

Detection thresholds (odor concentrations) were calculated following the ASTM (2001) and CEN (2003) standards. The panel detection threshold (DT) was calculated as the geometric mean of the panelists' DT values and reported as odor units per cubic meter (OU m^{-3}). Odor emission rates (OU h^{-1}) were calculated as the product of the ventilation airflow rate (m^3 h^{-1}) of the building and the difference between outlet and inlet odor concentrations (OU m^{-3}):

$$ER = OC \times VR \tag{1}$$

where ER is the odor emission rate (OU h^{-1}), OC is the odor concentration (OU m^{-3}), and VR is the ventilation rate at dry standard conditions (m^3 h^{-1}).

Odor emission rates were reported in terms of OU h^{-1} since odor samples were collected during a 1 h sampling period. These emission rates can be easily converted to OU s^{-1} if necessary. Fan airflow rates were calibrated *in situ* with the Fan Assessment Numeration System (FANS) (Jacobson et al., 2008; Bereznicki et al., 2012). The airflow rates were calculated for dry (0% relative humidity) standard conditions (0°C and 1 atm), as defined by the International Union of Pure and Applied Chemistry (IUPAC, 2012). One-minute averages of sixty 1 s readings of fan on/off status and/or speed, and differential static pressure were recorded every minute and used during post-

Table 1. Barn area, average animal number, and average animal mass.

Site[a]	Barn	Barn Area (m^2)	Average No. of Animals (head)	Average Animal Mass (kg $head^{-1}$)
WI5B	B1	2604	214 ±5.2	707 ±20.4
	B2	3210	348 ±9.3	703 ±0.0
IN5B	B1	13,688	1617 ±102	635 ±0.2
	B2	13,688	1754 ±25.1	635 ±0.0
IN3B	B1	732	1066 ±460	63 ±38
	B2	732	1086 ±451	62 ±40
IA4B	B1	2150	998 ±32.9	250 ±0.0
	B2	2150	1099 ±34.5	250 ±0.0
	B3	138.5	24 ±0.0	250 ±0.0

[a] At WI5B and IN5B, B1 and B2 were freestall dairy barns; at IN3B, B1 and B2 were swine finishing rooms; at IA4B, B1 and B2 were swine gestation barns and B3 was a swine farrowing room.

processing to calculate fan airflow rates and, by summation, the barn ventilation rates (Jin et al., 2012). Average airflow rates that corresponded to each location's sampling time (e.g., 60 min) were used to calculate odor emission rates. Odor emission rates were reported per barn area (OU h^{-1} m^{-2}), head (OU h^{-1} $head^{-1}$), and animal unit (OU^{-1} h^{-1} AU^{-1}).

Barn areas of the sites, average animal mass, and animal numbers are shown in table 1. One animal unit was 500 kg of live animal weight (Hoff et al., 2006). The animal mass and number varied during the year, and hourly averages (not overall averages) of animal mass and number were used to calculate odor emission rates.

Intensity

Panelists assessed intensity of a sample by matching it to one of a series of n-butanol solutions in water (0, 250, 750, 2250, 6750, and 20250 ppm n-butanol) contained in wide-necked glass bottles (reference scale method). Odor panelists were asked to rate the intensity of the odor in each sample using a 0 to 5 numerical scale where 0 = no odor, 1 = barely perceivable, 2 = faint but identifiable, 3 = easily perceivable, 4 = strong, and 5 = repulsive. The arithmetic average of intensity was calculated for each panel (Harssema, 1991).

Hedonic Tone

Hedonic tone was determined using a scale of -4 to +4 (-4, -3, -2, -1, 0, +1, +2, +3, and +4) where -4 = very unpleasant, 0 = neutral, and +4 = very pleasant. The arithmetic average of hedonic tone was calculated for each panel (VDI, 1992).

Seasonal Changes

To show seasonal changes, seasonal mean odor concentration, emission rate, odor intensity, and hedonic tone data are presented. Seasons were defined as follows: winter (four sampling events from 4 December 2007 to 31 January 2008 and four sampling events from 20 January to 24 February 2009), summer (four sampling events from 28 July to 9 September 2008), spring (four sampling events from 26 March to 29 May 2008 and five sampling events from 10 March to 7 May 2009), and fall (four sampling events from 22 October to 9 December 2008). Average ambient temperatures of the sites during sample collection are shown in table 2.

Table 2. Average ambient temperatures (°C).

Site	Winter	Summer	Spring	Fall
WI5B	-7.0 ±8.7	25.5 ±3.7	7.7 ±5.4	3.6 ±4.9
IN5B	-1.1 ±8.9	27.1 ±3.9	15.8 ±5.9	7.5 ±11.4
IN3B	-1.0 ±7.9	23.0 ±3.4	15.2 ±4.8	10.8 ±8.2
IA4B	-5.7 ±8.4	24.7 ±3.8	10.9 ±9.9	3.8 ±15.7

STATISTICAL ANALYSIS

Statistical analyses were conducted using JMP software (version 8.0.1, SAS Institute, Inc., Cary, N.C.). Data were log-normally distributed.

Ambient data (concentrations) were analyzed using season, species, and species/farm (farms were nested within species) as main effects. Barn data (concentrations and emission rates) was analyzed using season, species, species/farm, and species/farm/barn (barns or rooms were nested within farms, and farms were nested within species) as main effects. Barn concentrations were calculated by subtracting inlet air concentrations from the barn's exhaust air concentrations for each sampling day.

The differences between ambient concentrations or barn concentrations or barn emission rates were observed to be significant at 5% significance level if the difference was larger than the honestly significant difference (HSD). The HSD was calculated considering the interactions between the samples using the following equation (Oehlert, 2000):

$$\text{HSD} = \frac{q(No.of\ groups, df_{error})}{\sqrt{2}}\sqrt{\frac{\sigma_a{}^2+\frac{\sigma^2}{n_{r1}}}{n_{b1}}+\frac{\sigma_a{}^2+\frac{\sigma^2}{n_{r2}}}{n_{b2}}} \quad (2)$$

where σ_a^2 is the variance between location and laboratory interaction (variance due to interaction between the samples), σ^2 is the variance within location and laboratory (variance due to differences within samples), n_{ri} is the number of replicates, n_{bi} is the number of measurements (excluding replicates) for each season/species/farm/barn, q is the Studentized range statistic, df_{error} is the error degrees of freedom, and *No. of groups* is four seasons, two species, four farms, and nine barns.

RESULTS AND DISCUSSION

COMPARISON OF BARN INLET ODOR CONCENTRATIONS

Mean inlet odor concentrations ranged from 8 to 128 OU m^{-3} at WI5B, from 14 to 154 OU m^{-3} at IN5B, from 25 to 657 OU m^{-3} at IN3B, and from 22 to 582 OU m^{-3} at IA4B (fig. 1). No significant differences were observed between seasons (differences between means < $HSD_{seasons}$ = 0.22), but significant differences were observed among farms. Results showed that barn inlet odor concentrations at swine sites were significantly higher than at dairy sites (differences between means > $HSD_{species}$ = 0.12). The highest odor concentrations were measured at IA4B (swine). This might have been due to high odor emission rates from the sow gestation barns at this site. The second, third, and fourth highest inlet odor concentrations were measured at IN3B (swine), IN5B (dairy), and WI5B (dairy), respectively (fig. 1).

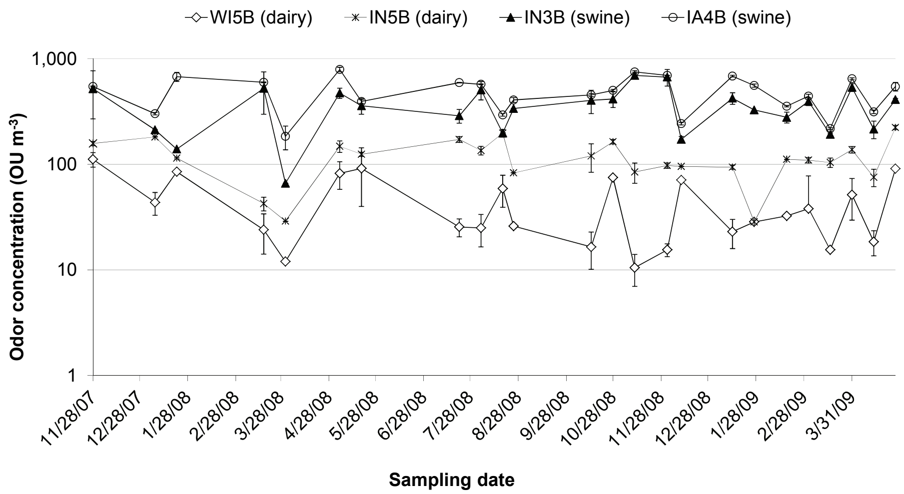

Figure 1. Barn inlet air odor concentrations of sites WI5B (freestall dairy), IN5B (freestall dairy), IN3B (swine finishing), and IA4B (barns 1 and 2 were swine gestation barns, and barn 3 was a farrowing barn). Averages of two measurements for each sampling day are reported (total of 25 sampling days per site). The *y*-axis is a log scale.

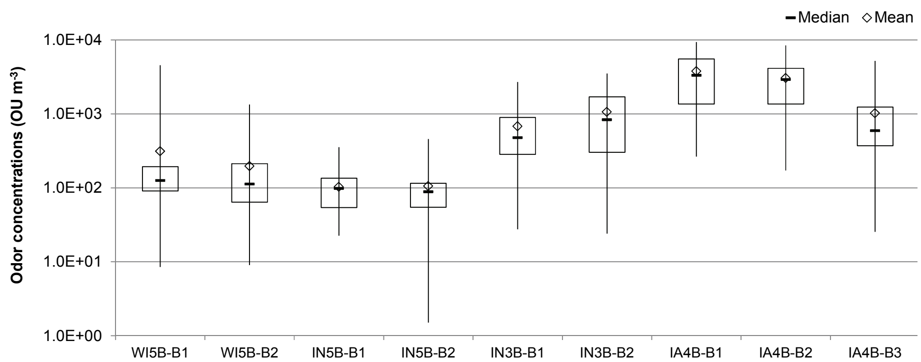

Figure 2. Odor concentrations of WI5B (freestall dairy), IN5B (freestall dairy), IN3B (swine finishing), and IA4B (barns 1 and 2 were gestation barns, and barn 3 was a farrowing room). Odor concentrations were calculated by subtracting barn inlet concentrations from exhaust air concentrations. Box plots represent 25th, 50th (median), and 75th percentiles. Means are shown by diamonds (◊). The *y*-axis is a log scale.

COMPARISON OF BARN ODOR CONCENTRATIONS AND EMISSION RATES

The mean, median, minimum, maximum, 25th percentile, and 75th percentile barn odor concentrations (OU m^{-3}) and emission rates (OU h^{-1} m^{-2}, OU h^{-1} $head^{-1}$, and OU h^{-1} AU^{-1}) are given in figures 2 and 3, respectively. The mean odor concentrations of the dairy barns at WI5B and IN5B ranged from 103 to 312 OU m^{-3}. These were similar to the average odor concentration 112 ±280 OU m^{-3} measured in two large freestall dairies in Ohio (Zhao et al., 2007).

The mean odor concentrations of the finishing barns (IN3B) were 6.8×10^2 (barn 1) and 1.1×10^3 (barn 2) OU m^{-3}, and the mean odor concentrations of the gestation barns (IA4B) were 3.8×10^3 (barn 1) and 3.1×10^3 (barn 2) OU m^{-3}. Finally, the mean odor concentration of the farrowing room (barn 3 at IA4B) was 1.0×10^3 OU m^{-3}. Odor concentrations of the finishing barns were slightly lower than the values reported in the literature. Guo et al. (2011) and Sun et al. (2010) reported odor concentrations of the finishing barns as $1.1 \times 10^3 \pm 7.5 \times 10^2$ and $1.9 \times 10^3 \pm 1.2 \times 10^3$ OU m^{-3}, respectively. Odor concentrations of the gestation barns were much higher than the values reported in the literature, which were between 9.3×10^2 and 1.5×10^3 OU m^{-3} (Guo et al., 2011; Rahman and Newman, 2012). This might be due to the unusually high H_2S concentrations of the barns (Akdeniz et al., 2012). Odor concentrations of the farrowing barn was lower than the values reported by Rahman and Newman (2012), which were between 6.3×10^2 and 7.0×10^2 OU m^{-3}, but in the same range as the value reported by Guo et al. (2011), which was 2.0×10^3 OU m^{-3}.

The mean emission rates in OU h^{-1} m^{-2}, OU h^{-1} $head^{-1}$, and OU h^{-1} AU^{-1} ranged from 7.1×10^3 to 1.5×10^5, from 4.1×10^4 to 3.3×10^5, and from 4.6×10^4 to 6.6×10^5, respectively. As expected, high variations in odor concentrations and emission rates were observed (Guo et al., 2006, 2007; Sun et al., 2010; Guo et al., 2011; Rahman and Newman, 2012; Schauberger et al., 2012), and significant differences ($p < 0.05$) among seasons, sites, buildings, and species were observed (discussed in the following sections).

COMPARISON OF SEASONS

Seasonal averages of the ventilation rates (m^3 h^{-1}), barn odor concentrations (OU m^{-3}), and barn emission rates (OU h^{-1} m^{-2}, OU h^{-1} $head^{-1}$, and OU h^{-1} AU^{-1}) are shown in tables 3 through 7. Seasonal averages of hedonic tone and odor intensity are given in tables 8 and 9. Arithmetic means

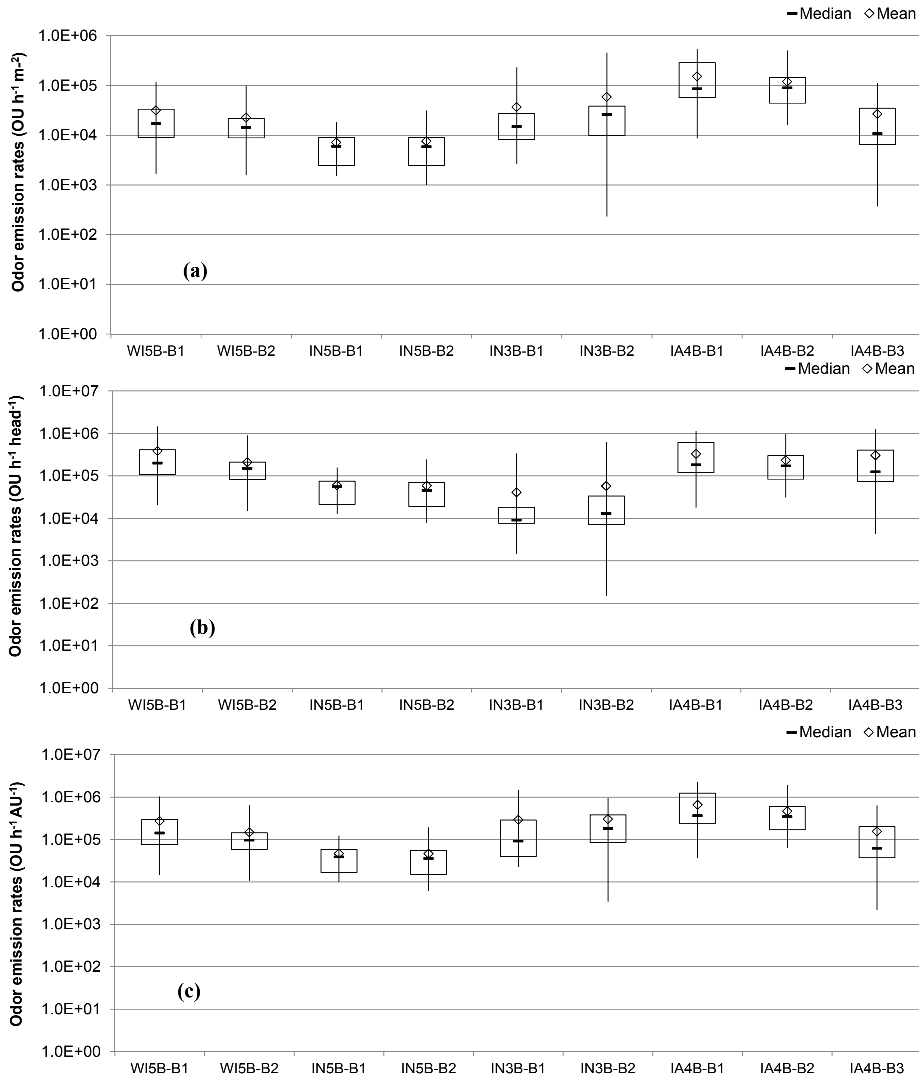

Figure 3. Odor emission rates of WI5B (freestall dairy), IN5B (freestall dairy), IN3B (swine finishing), and IA4B (barns 1 and 2 were swine gestation barns, and barn 3 was a farrowing barn). Box plots represent the 25th, 50th (median), and 75th percentiles. Means are shown by diamonds (◊). The *y*-axis is a log scale.

Table 3. Seasonal averages of airflow rates ($m^3\ h^{-1}$) at dry standard conditions.

Site[a]	Barn	Winter	Summer	Spring	Fall	Overall Average
WI5B	B1	$1.2{\times}10^5 \pm 3.7{\times}10^4$	$1.0{\times}10^6 \pm 2.6{\times}10^5$	$3.4{\times}10^5 \pm 1.1{\times}10^5$	$3.0{\times}10^5 \pm 1.0{\times}10^5$	$4.8{\times}10^5 \pm 3.1{\times}10^5$
	B2	$1.2{\times}10^5 \pm 4.2{\times}10^4$	$1.2{\times}10^6 \pm 3.3{\times}10^5$	$3.8{\times}10^5 \pm 1.3{\times}10^5$	$3.5{\times}10^5 \pm 1.4{\times}10^5$	
IN5B	B1	$5.1{\times}10^5 \pm 9.0{\times}10^4$	$1.5{\times}10^6 \pm 9.1{\times}10^5$	$8.8{\times}10^5 \pm 3.8{\times}10^5$	$5.7{\times}10^5 \pm 2.1{\times}10^5$	$9.3{\times}10^5 \pm 4.7{\times}10^5$
	B2	$5.6{\times}10^5 \pm 1.9{\times}10^5$	$1.9{\times}10^6 \pm 7.4{\times}10^5$	$7.9{\times}10^5 \pm 1.0{\times}10^5$	$7.3{\times}10^5 \pm 1.7{\times}10^5$	
IN3B	B1	$2.0{\times}10^4 \pm 8.7{\times}10^3$	$7.6{\times}10^4 \pm 7.1{\times}10^4$	$5.0{\times}10^4 \pm 4.3{\times}10^5$	$3.5{\times}10^4 \pm 2.1{\times}10^4$	$4.8{\times}10^4 \pm 4.1{\times}10^4$
	B2	$1.5{\times}10^4 \pm 4.1{\times}10^3$	$1.0{\times}10^5 \pm 7.4{\times}10^4$	$4.8{\times}10^4 \pm 5.2{\times}10^5$	$3.5{\times}10^4 \pm 2.2{\times}10^4$	
IA4B	B1	$3.9{\times}10^4 \pm 1.4{\times}10^4$	$1.6{\times}10^5 \pm 6.2{\times}10^4$	$8.9{\times}10^4 \pm 4.6{\times}10^4$	$6.7{\times}10^4 \pm 4.2{\times}10^4$	$9.6{\times}10^4 \pm 5.7{\times}10^4$
	B2	$3.6{\times}10^4 \pm 1.5{\times}10^4$	$2.1{\times}10^5 \pm 5.9{\times}10^3$	$8.5{\times}10^4 \pm 5.2{\times}10^4$	$7.6{\times}10^4 \pm 4.8{\times}10^4$	
	B3	$3.3{\times}10^3 \pm 3.7{\times}10^3$	$6.5{\times}10^3 \pm 2.4{\times}10^3$	$2.7{\times}10^3 \pm 1.6{\times}10^3$	$1.4{\times}10^3 \pm 1.2{\times}10^3$	$3.5{\times}10^3 \pm 2.7{\times}10^3$
Overall average		$1.6{\times}10^5 \pm 2.1{\times}10^5$	$6.9{\times}10^5 \pm 8.1{\times}10^5$	$3.0{\times}10^5 \pm 3.6{\times}10^5$	$2.4{\times}10^5 \pm 2.7{\times}10^5$	

[a] At WI5B and IN5B, B1 and B2 were freestall dairy barns; at IN3B, B1 and B2 were swine finishing rooms; at IA4B, B1 and B2 were swine gestation barns and B3 is a swine farrowing room.

of seasons and sites are shown at the bottom and on the right side of the tables, respectively.

Seasonal averages of ventilation rates (VRs) measured during odor sampling are shown in table 3. The highest VRs ($9.3 \times 10^5\ m^3\ h^{-1}$) were measured at IN5B, while the lowest VRs ($4.8 \times 10^4\ m^3\ h^{-1}$) were measured in the swine finishing rooms at IN3B and the farrowing room ($3.5 \times 10^3\ m^3\ h^{-1}$) at IA4B (table 3). The lowest VRs were measured in winter, except in the farrowing room at IA4B where VRs were lowest during fall odor sampling. This unusual case may have been caused by the animal flow (sows just farrowed, thus very young piglets) during the sampling periods. The highest VRs were measured in summer at the dairy sites (WI5B and IN5B) and in summer and spring at

Table 4. Seasonal and overall averages of barn odor concentrations (OU m^{-3}).

Site[a]	Barn	Winter	Summer	Spring	Fall	Overall Average[b]
WI5B	B1	$3.1\times10^{2} \pm 3.7\times10^{2}$	$1.8\times10^{2} \pm 7.3\times10^{1}$	$2.9\times10^{2} \pm 3.6\times10^{2}$	$6.6\times10^{2} \pm 1.4\times10^{3}$	$3.0\times10^{2} \pm 5.2\times10^{2}$ c
	B2	$2.0\times10^{2} \pm 1.7\times10^{2}$	$1.5\times10^{2} \pm 1.1\times10^{2}$	$2.9\times10^{2} \pm 2.9\times10^{2}$	$3.1\times10^{2} \pm 3.4\times10^{2}$	
IN5B	B1	$1.5\times10^{2} \pm 5.7\times10^{1}$	$1.9\times10^{2} \pm 3.1\times10^{1}$	$2.1\times10^{2} \pm 9.0\times10^{1}$	$1.7\times10^{2} \pm 5.8\times10^{1}$	$1.7\times10^{2} \pm 8.9\times10^{1}$ d
	B2	$1.5\times10^{2} \pm 6.3\times10^{1}$	$1.9\times10^{2} \pm 4.8\times10^{1}$	$1.5\times10^{2} \pm 1.5\times10^{2}$	$1.3\times10^{2} \pm 3.2\times10^{1}$	
IN3B	B1	$8.0\times10^{2} \pm 6.7\times10^{2}$	$1.9\times10^{3} \pm 6.5\times10^{2}$	$1.0\times10^{3} \pm 6.9\times10^{2}$	$9.1\times10^{2} \pm 6.7\times10^{2}$	$1.3\times10^{3} \pm 8.3\times10^{2}$ b
	B2	$1.3\times10^{3} \pm 1.1\times10^{3}$	$1.4\times10^{3} \pm 8.9\times10^{2}$	$1.1\times10^{3} \pm 8.6\times10^{2}$	$1.6\times10^{3} \pm 1.1\times10^{3}$	
IA4B	B1	$3.5\times10^{3} \pm 1.7\times10^{3}$	$3.6\times10^{3} \pm 3.0\times10^{3}$	$4.7\times10^{3} \pm 2.2\times10^{3}$	$3.1\times10^{3} \pm 3.1\times10^{3}$	$3.5\times10^{3} \pm 2.3\times10^{3}$ a
	B2	$4.6\times10^{3} \pm 2.7\times10^{3}$	$2.4\times10^{3} \pm 1.8\times10^{3}$	$3.6\times10^{3} \pm 1.6\times10^{3}$	$2.2\times10^{3} \pm 2.0\times10^{3}$	
	B3	$1.2\times10^{3} \pm 9.4\times10^{2}$	$1.2\times10^{3} \pm 1.3\times10^{3}$	$9.6\times10^{2} \pm 1.1\times10^{3}$	$1.2\times10^{3} \pm 9.4\times10^{2}$	$1.2\times10^{3} \pm 1.1\times10^{3}$ b
Overall average[b]		$1.4\times10^{3} \pm 1.8\times10^{3}$ a	$1.2\times10^{3} \pm 1.7\times10^{3}$ b	$1.4\times10^{3} \pm 1.7\times10^{3}$ a	$1.1\times10^{3} \pm 1.5\times10^{3}$ c	

[a] At WI5B and IN5B, B1 and B2 were freestall dairy barns; at IN3B, B1 and B2 were swine finishing rooms; at IA4B, B1 and B2 were swine gestation barns and B3 was a swine farrowing room.

[b] Overall seasonal averages or overall site averages followed by different letters are significantly different ($p < 0.05$).

Table 5. Seasonal and overall averages of area-specific odor emissions (OU h^{-1} m^{-2}).

Site[a]	Barn	Winter	Summer	Spring	Fall	Overall Average[b]
WI5B	B1	$2.9\times10^{4} \pm 4.1\times10^{4}$	$6.3\times10^{4} \pm 2.5\times10^{4}$	$2.8\times10^{4} \pm 3.3\times10^{4}$	$1.2\times10^{4} \pm 4.5\times10^{3}$	$3.0\times10^{4} \pm 2.9\times10^{4}$ c
	B2	$1.1\times10^{4} \pm 1.1\times10^{4}$	$5.5\times10^{4} \pm 4.1\times10^{4}$	$2.5\times10^{4} \pm 1.9\times10^{4}$	$1.4\times10^{4} \pm 4.2\times10^{3}$	
IN5B	B1	$3.9\times10^{3} \pm 2.0\times10^{3}$	$8.7\times10^{3} \pm 6.8\times10^{3}$	$1.0\times10^{4} \pm 5.4\times10^{3}$	$3.7\times10^{3} \pm 3.8\times10^{3}$	$6.8\times10^{3} \pm 6.2\times10^{3}$ d
	B2	$5.1\times10^{3} \pm 3.2\times10^{3}$	$1.1\times10^{4} \pm 6.6\times10^{3}$	$1.0\times10^{4} \pm 9.0\times10^{3}$	$1.7\times10^{3} \pm 8.0\times10^{2}$	
IN3B	B1	$1.0\times10^{4} \pm 6.6\times10^{3}$	$1.4\times10^{5} \pm 9.5\times10^{4}$	$1.9\times10^{4} \pm 8.2\times10^{3}$	$2.5\times10^{4} \pm 3.6\times10^{4}$	$6.7\times10^{4} \pm 8.8\times10^{4}$ b
	B2	$1.9\times10^{4} \pm 1.2\times10^{4}$	$2.4\times10^{5} \pm 2.3\times10^{5}$	$2.3\times10^{4} \pm 1.7\times10^{4}$	$5.2\times10^{4} \pm 5.1\times10^{4}$	
IA4B	B1	$6.2\times10^{4} \pm 2.8\times10^{4}$	$2.6\times10^{5} \pm 2.2\times10^{5}$	$1.9\times10^{5} \pm 1.2\times10^{5}$	$1.1\times10^{5} \pm 1.4\times10^{5}$	$1.4\times10^{5} \pm 1.3\times10^{5}$ a
	B2	$6.0\times10^{4} \pm 3.3\times10^{4}$	$2.5\times10^{5} \pm 2.1\times10^{5}$	$1.2\times10^{5} \pm 6.1\times10^{4}$	$8.7\times10^{4} \pm 8.1\times10^{4}$	
	B3	$2.8\times10^{4} \pm 3.9\times10^{4}$	$5.0\times10^{4} \pm 5.3\times10^{4}$	$2.0\times10^{4} \pm 2.3\times10^{4}$	$9.4\times10^{3} \pm 3.9\times10^{3}$	$2.7\times10^{4} \pm 3.3\times10^{4}$ c
Overall average[b]		$2.5\times10^{4} \pm 3.2\times10^{4}$ c	$1.2\times10^{5} \pm 1.5\times10^{5}$ a	$5.0\times10^{4} \pm 7.8\times10^{4}$ b	$3.5\times10^{4} \pm 6.4\times10^{4}$ c	

[a] At WI5B and IN5B, B1 and B2 were freestall dairy barns; at IN3B, B1 and B2 were swine finishing rooms; at IA4B, B1 and B2 were swine gestation barns and B3 was a swine farrowing room.

[b] Overall seasonal averages or overall site averages followed by different letters are significantly different ($p < 0.05$).

Table 6. Seasonal and overall averages of animal-specific odor emissions (OU h^{-1} $head^{-1}$).

Site[a]	Barn	Winter	Summer	Spring	Fall	Overall Average[b]
WI5B	B1	$2.0\times10^{5} \pm 1.0\times10^{5}$	$7.7\times10^{5} \pm 3.0\times10^{5}$	$3.4\times10^{5} \pm 4.1\times10^{5}$	$1.4\times10^{5} \pm 4.8\times10^{4}$	$3.0\times10^{5} \pm 3.4\times10^{5}$ a
	B2	$1.0\times10^{5} \pm 9.8\times10^{4}$	$5.0\times10^{5} \pm 3.7\times10^{5}$	$2.3\times10^{5} \pm 1.7\times10^{5}$	$1.5\times10^{5} \pm 5.7\times10^{4}$	
IN5B	B1	$3.6\times10^{4} \pm 2.2\times10^{4}$	$7.1\times10^{4} \pm 5.6\times10^{4}$	$8.5\times10^{4} \pm 4.6\times10^{4}$	$3.0\times10^{4} \pm 3.1\times10^{4}$	$5.5\times10^{4} \pm 5.0\times10^{4}$ c
	B2	$4.0\times10^{4} \pm 2.5\times10^{4}$	$8.3\times10^{4} \pm 5.1\times10^{4}$	$8.0\times10^{4} \pm 7.1\times10^{4}$	$1.4\times10^{4} \pm 6.2\times10^{3}$	
IN3B	B1	$8.5\times10^{3} \pm 4.0\times10^{3}$	$2.0\times10^{5} \pm 1.6\times10^{5}$	$1.1\times10^{4} \pm 6.1\times10^{3}$	$1.8\times10^{4} \pm 2.6\times10^{4}$	$7.3\times10^{4} \pm 1.2\times10^{5}$ c
	B2	$2.1\times10^{4} \pm 1.6\times10^{4}$	$2.8\times10^{5} \pm 3.2\times10^{5}$	$1.3\times10^{4} \pm 1.1\times10^{4}$	$3.6\times10^{4} \pm 3.6\times10^{4}$	
IA4B	B1	$1.3\times10^{5} \pm 6.2\times10^{4}$	$5.3\times10^{5} \pm 4.7\times10^{5}$	$4.3\times10^{5} \pm 2.6\times10^{5}$	$2.4\times10^{5} \pm 3.1\times10^{5}$	$2.9\times10^{5} \pm 2.6\times10^{5}$ a
	B2	$1.2\times10^{5} \pm 6.4\times10^{4}$	$4.7\times10^{5} \pm 3.9\times10^{5}$	$2.4\times10^{5} \pm 1.2\times10^{5}$	$1.7\times10^{5} \pm 1.7\times10^{5}$	
	B3	$1.6\times10^{5} \pm 2.1\times10^{5}$	$2.9\times10^{5} \pm 3.0\times10^{5}$	$1.2\times10^{5} \pm 1.3\times10^{5}$	$5.4\times10^{4} \pm 2.2\times10^{4}$	$1.6\times10^{5} \pm 1.9\times10^{5}$ b
Overall average[b]		$9.1\times10^{4} \pm 2.1\times10^{4}$ c	$3.5\times10^{5} \pm 3.5\times10^{5}$ a	$1.7\times10^{5} \pm .3\times10^{5}$ b	$9.5\times10^{4} \pm 1.3\times10^{5}$ c	

[a] At WI5B and IN5B, B1 and B2 were freestall dairy barns; at IN3B, B1 and B2 were swine finishing rooms; at IA4B, B1 and B2 were swine gestation barns and B3 was a swine farrowing room.

[b] Overall seasonal averages or overall site averages followed by different letters are significantly different ($p < 0.05$).

Table 7. Seasonal and overall averages of live mass specific odor emissions (OU h^{-1} AU^{-1}).

Site[a]	Barn	Winter	Summer	Spring	Fall	Overall Average[b]
WI5B	B1	$2.6\times10^{5} \pm 3.6\times10^{5}$	$5.5\times10^{5} \pm 2.2\times10^{5}$	$2.4\times10^{5} \pm 2.9\times10^{5}$	$1.0\times10^{5} \pm 3.4\times10^{4}$	$2.3\times10^{5} \pm 2.4\times10^{5}$ b
	B2	$7.1\times10^{4} \pm 6.9\times10^{4}$	$3.5\times10^{5} \pm 2.7\times10^{5}$	$1.6\times10^{5} \pm 1.2\times10^{5}$	$9.2\times10^{4} \pm 2.7\times10^{4}$	
IN5B	B1	$2.6\times10^{4} \pm 1.3\times10^{4}$	$5.6\times10^{4} \pm 4.4\times10^{4}$	$6.7\times10^{4} \pm 3.6\times10^{4}$	$2.4\times10^{4} \pm 2.4\times10^{4}$	$4.3\times10^{4} \pm 3.9\times10^{4}$ c
	B2	$3.2\times10^{4} \pm 2.0\times10^{4}$	$6.6\times10^{4} \pm 4.0\times10^{4}$	$6.3\times10^{4} \pm 5.6\times10^{4}$	$1.1\times10^{4} \pm 4.9\times10^{3}$	
IN3B	B1	$6.1\times10^{4} \pm 3.5\times10^{4}$	$1.2\times10^{6} \pm 2.6\times10^{5}$	$1.9\times10^{5} \pm 1.2\times10^{5}$	$1.2\times10^{5} \pm 1.3\times10^{5}$	$3.8\times10^{5} \pm 3.7\times10^{5}$ b
	B2	$9.7\times10^{4} \pm 7.1\times10^{4}$	$7.2\times10^{5} \pm 3.4\times10^{5}$	$3.1\times10^{5} \pm 3.1\times10^{5}$	$2.7\times10^{5} \pm 1.6\times10^{5}$	
IA4B	B1	$2.7\times10^{5} \pm 1.2\times10^{5}$	$1.1\times10^{6} \pm 9.3\times10^{5}$	$8.5\times10^{5} \pm 5.2\times10^{5}$	$4.8\times10^{5} \pm 6.1\times10^{5}$	$5.8\times10^{5} \pm 5.2\times10^{5}$ a
	B2	$2.3\times10^{5} \pm 1.3\times10^{5}$	$9.4\times10^{5} \pm 7.8\times10^{5}$	$4.9\times10^{5} \pm 2.4\times10^{4}$	$3.5\times10^{5} \pm 3.3\times10^{5}$	
	B3	$3.3\times10^{5} \pm 2.2\times10^{5}$	$5.8\times10^{5} \pm 6.1\times10^{5}$	$2.3\times10^{5} \pm 2.6\times10^{5}$	$1.1\times10^{5} \pm 4.5\times10^{4}$	$3.1\times10^{5} \pm 3.9\times10^{5}$ b
Overall average[b]		$1.5\times10^{5} \pm 2.3\times10^{5}$ c	$6.2\times10^{5} \pm 5.9\times10^{5}$ a	$2.9\times10^{5} \pm 3.5\times10^{5}$ b	$1.7\times10^{5} \pm 2.6\times10^{5}$ c	

[a] At WI5B and IN5B, B1 and B2 were freestall dairy barns; at IN3B, B1 and B2 were swine finishing rooms; at IA4B, B1 and B2 were swine gestation barns and B3 was a swine farrowing room.

[b] Overall seasonal averages or overall site averages followed by different letters are significantly different ($p < 0.05$).

the swine sites. When overall VRs were considered, the highest VRs, as expected, were calculated for summer, which was followed by spring, fall, and winter (table 3).

Seasonal averages of barn concentrations are shown in table 4. No apparent seasonal pattern was observed for odor concentrations of the barns/rooms. For instance, the highest odor concentrations of room 1 at IN3B were measured in summer, while the highest odor concentrations of room 2 were measured in fall. However, when the overall odor concentrations across all sites were considered, the highest

Table 8. Seasonal and overall averages of barn hedonic tone (hedonic tone varied from -4 to +4).

Site[a]	Barn	Winter	Summer	Spring	Fall	Overall Average[b]
WI5B	B1	-1.3 ±0.5	-1.2 ±0.6	-1.4 ±0.6	-2.2 ±1.1	-1.6 ±0.8 ab
	B2	-1.3 ±0.5	-1.1 ±0.3	-1.4 ±0.5	-2.6 ±1.1	
IN5B	B1	-1.4 ±0.3	-1.5 ±0.4	-1.4 ±0.3	-1.6 ±0.4	-1.5 ±0.4 a
	B2	-1.5 ±0.3	-1.6 ±0.3	-1.4 ±0.3	-1.5 ±0.5	
IN3B	B1	-2.2 ±0.7	-2.0 ±0.3	-2.1 ±0.6	-1.8 ±0.2	-2.1 ±0.5 b
	B2	-2.2 ±0.6	-1.9 ±0.3	-2.1 ±0.4	-2.1 ±0.3	
IA4B	B1	-2.7 ±0.7	-2.9 ±0.5	-2.3 ±0.2	-2.2 ±2.1	-2.6 ±0.8 c
	B2	-2.7 ±0.3	-2.5 ±0.5	-2.5 ±0.7	-2.6 ±0.4	
	B3	-2.3 ±0.4	-2.4 ±0.6	-2.1 ±0.5	-2.5 ±0.2	-2.3 ±0.5 c
Overall average[b]		-2.0 ±0.7 a	-1.9 ±0.6 a	-1.9 ±0.7 a	-2.1 ±0.9 a	

[a] At WI5B and IN5B, B1 and B2 were freestall dairy barns; at IN3B, B1 and B2 were swine finishing rooms; at IA4B, B1 and B2 were swine gestation barns and B3 was a swine farrowing room.

[b] Overall seasonal averages or overall site averages followed by different letters are significantly different ($p < 0.05$).

Table 9. Seasonal averages of odor intensity (odor intensity range was 0 to 5 with 5 being the most intense).

Site[a]	Barn	Winter	Summer	Spring	Fall	Overall Average[b]
WI5B	B1	2.8 ±0.4	2.4 ±0.5	2.1 ±0.4	1.9 ±0.5	2.3 ±0.4 c
	B2	2.6 ±0.4	2.3 ±0.2	2.1 ±0.4	2.4 ±0.5	
IN5B	B1	2.1 ±0.5	1.8 ±0.4	1.7 ±0.3	1.8 ±0.6	1.9 ±0.5 d
	B2	2.2 ±0.5	1.9 ±0.2	1.7 ±0.2	1.8 ±0.6	
IN3B	B1	2.4 ±0.7	2.6 ±0.5	2.4 ±0.6	2.7 ±0.5	2.4 ±0.6 bc
	B2	2.4 ±0.6	2.2 ±0.5	2.0 ±0.4	2.8 ±0.4	
IA4B	B1	3.2 ±0.4	3.1 ±0.4	3.3 ±0.5	3.3 ±0.5	3.1 ±0.5 a
	B2	3.1 ±0.5	2.8 ±0.6	3.0 ±0.5	3.1 ±0.6	
	B3	2.7 ±0.5	2.6 ±0.4	3.0 ±0.6	2.8 ±0.5	2.8 ±0.5 ab
Overall average[b]		2.6 ±0.6 a	2.4 ±0.7 a	2.4 ±0.6 a	2.5 ±0.7 a	

[a] At WI5B and IN5B, B1 and B2 were freestall dairy barns; at IN3B, B1 and B2 were swine finishing rooms; at IA4B, B1 and B2 were swine gestation barns and B3 was a swine farrowing room.

[b] Overall seasonal averages or overall site averages followed by different letters are significantly different ($p < 0.05$).

odor concentrations occurred in winter (1.4×10^3 OU m^{-3}) and spring (1.4×10^3 OU m^{-3}) (no significant difference between these two seasons), and the lowest concentrations were measured in summer (1.2×10^3 OU m^{-3}) and fall (1.1×10^3 OU m^{-3}) (table 4). These results were similar to those of Guo et al. (2006, 2011), who measured odor concentrations of swine gestation, farrowing, nursery, and finishing rooms and reported that odor concentrations of the swine barns were high in winter when ventilation rate was low and low in summer when ventilation rate was high.

Seasonal averages of the barn odor emission rates are shown in tables 5 through 7. The highest building emission rates in all three units (OU h^{-1} m^{-2}, OU h^{-1} head^{-1}, and OU h^{-1} AU^{-1}) were measured in summer and spring. The lowest emission rates were measured in winter. When the overall emission rates (including all sites) were calculated, it was observed that the emission rates in summer were significantly higher (1.2×10^5 OU h^{-1} m^{-2}, 3.5×10^5 OU h^{-1} head^{-1}, and 6.2×10^5 OU h^{-1} AU^{-1}) than during other seasons. The second highest emission rates were measured in spring (5.0×10^4 OU h^{-1} m^{-2}, 1.7×10^5 OU h^{-1} head^{-1}, and 2.9×10^5 OU h^{-1} AU^{-1}), followed by fall and winter. This may have been due to increased ventilation rates and microbial activities in higher temperatures compared with winter and fall. Guo et al. (2006, 2011) and Yu et al. (2010) also reported that odor emission rates of the swine barns varied significantly throughout the year, but apparent seasonal patterns were not observed. Schauberger et al. (2012) described a model that standardizes measurements to account for the significant effects of indoor temperature and house ventilation rate.

Seasonal averages of the hedonic tone and intensity measurements are shown in tables 8 and 9, respectively. Overall seasonal averages of hedonic tone and odor intensity in exhaust air were -2.0 (unpleasant odor) and 2.6 (between weak and distinct odor) in winter and -1.9 and 2.4 in summer, respectively. Surprisingly, no significant differences in hedonic tone and odor intensity between seasons were observed.

Comparison of Farms

Barn odor emission rates at the dairy and swine sites are shown in figures 4 and 5, respectively. The site averages of identical barns are reported for each sampling day.

Odor concentrations (OU m^{-3}) and animal specific, live mass specific, emission rates of the dairy sites were different from each other (tables 4 through 7, fig. 4). Odor emission rates of the IN5B barns were significantly lower than the emission rates of the WI5B barns. Overall average emission rates were 3.0×10^4 OU h^{-1} m^{-2}, 3.0×10^5 OU h^{-1} head^{-1}, and 2.3×10^5 OU h^{-1} AU^{-1} at WI5B and 6.8×10^3 OU h^{-1} m^{-2}, 5.5×10^4 OU h^{-1} head^{-1}, and 4.3×10^4 OU h^{-1} AU^{-1} at IN5B (tables 5 through 7). The WI5B barns exhibited higher odor intensity (overall average = 2.3) than the IN5B barns (table 9). There was no significant difference between average hedonic tones of -1.6 at WI5B and -1.5 at IN5B.

Manure removal frequencies (every 8 h) and management systems (tractor scrape) of the dairy sites were similar in the second year of the project (after September 2008). But in the first year of the project, manure management at WI5B was a manure effluent flush system. Differences in manure management systems could have affected odor emission rates. It was also observed that switching from a manure effluent flushing system in year 1 to a tractor

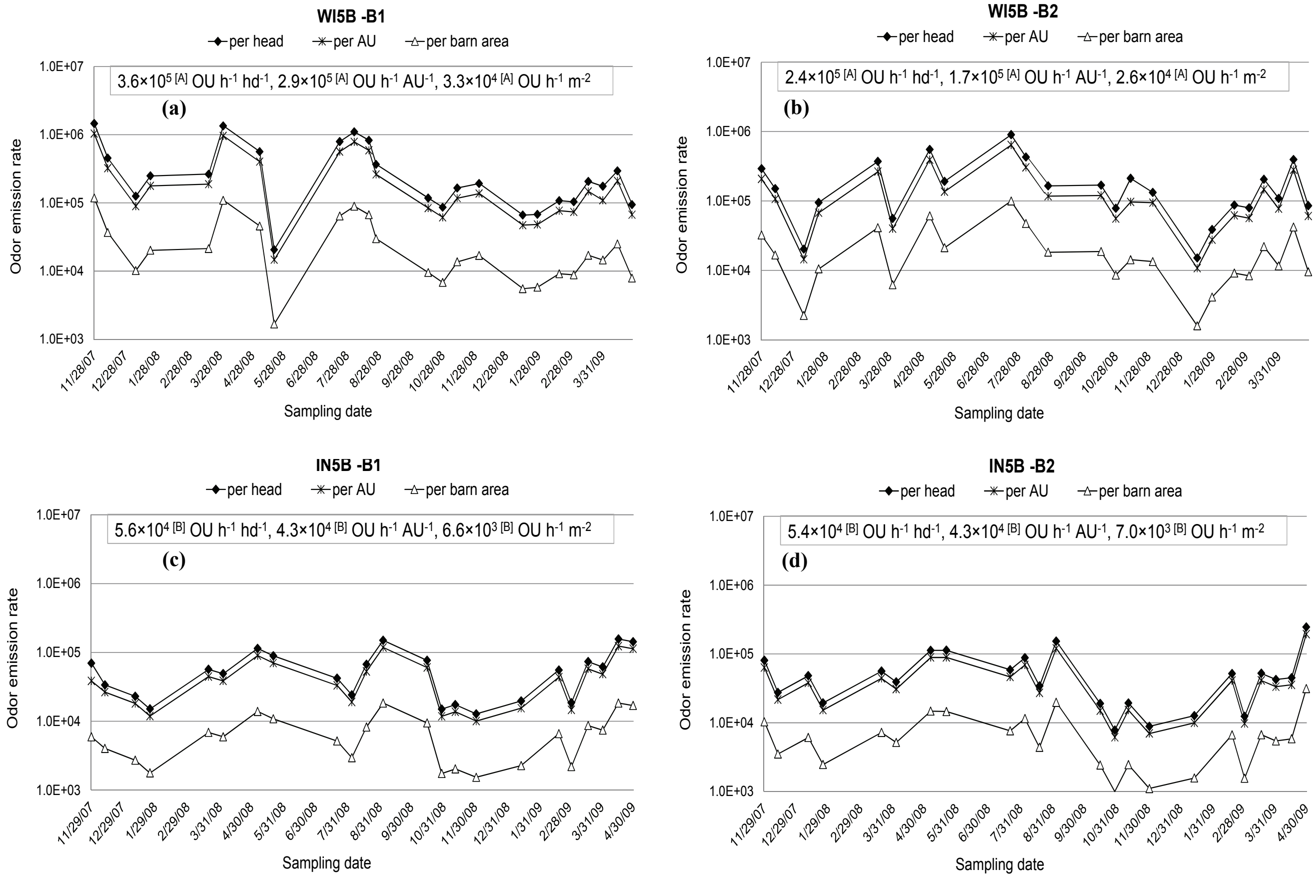

Figure 4. Average barn odor emission rates at freestall dairy sites WI5B and IN5B. Averages of three measurements are reported for each sampling day (total of 25 sampling days per site). Overall average emission rate values (shown in boxes) followed by different letters are significantly different ($p < 0.05$). Emission rates in OU h^{-1} m^{-2}, OU h^{-1} head^{-1}, and OU h^{-1} AU^{-1} were evaluated separately. The *y*-axis is a log scale.

scrape system in year 2 caused significant reduction in H_2S and odor emissions at WI5B (figs. 4a and 4b). This finding was consistent with the literature. Changing from a flush system to a scraper system has been shown to be effective in reducing odor emissions from freestall dairy and tunnel-ventilated swine finisher barns (Parker, 2008, 2010).

In addition, the bedding types of the two dairy sites were different. The bedding type at WI5B was wood shavings and sand (wood shavings until September 2008 and sand afterwards), and the bedding type at IN5B was digested manure solids (Bereznicki et al., 2012). Although sand is known to be the most comfortable bedding for dairy cows, its absorbance capacity is not as high as other organic materials (Misselbrook and Powell, 2005), so it might have caused higher barn odor emissions at WI5B.

Differences in odor concentrations and emissions rates (OU h^{-1} m^{-2}, OU h^{-1} head^{-1}, and OU h^{-1} AU^{-1}) between the swine sites were also significant. Odor emissions from the swine finishing rooms of IN3B were significantly lower than the odor emissions of the sow gestation barns of IA4B (fig. 5). Overall average odor emission rates of IN3B were 6.7×10^4 OU h^{-1} m^{-2}, 7.3×10^4 OU h^{-1} head^{-1}, and 3.8×10^5 OU h^{-1} AU^{-1}, and overall averages of the sow gestation barns of IA4B were 1.4×10^5 OU h^{-1} m^{-2}, 2.9×10^5 OU h^{-1} head^{-1}, and 5.8×10^5 OU h^{-1} AU^{-1} (tables 5 through 7). In addition, lower hedonic tone (less pleasant) and higher odor intensities were measured for the sow gestation barns compared to the finishing barns (tables 8 and 9).

Management characteristics of the swine buildings were similar. The floor type was slatted, the ventilation type was mechanical tunnel ventilation, manure storage was an underfloor deep pit, and manure was removed from the pit twice a year, or every 180 days. The numbers of animals in these barns were also similar (about 2,152 head at IN3B and 2,097 head at IA4B). However, as expected, the average mass of the gestation sows (250 kg head^{-1}) was higher than the average mass of the finishing pigs (62.5 kg head^{-1}). The diets fed finishing pigs versus gestation sows were quite different, with the first being fed *ad libitum* to maximize growth and the second only a restricted maintenance ration.

These findings were consistent with Jacobson et al. (2001), who listed odor emission rates from North American swine facilities and reported higher odor emission rates for gestation sows (between 1.7×10^4 and 7.7×10^4 OU h^{-1} m^{-2}) compared with finishing pigs (between 7.6×10^3 and 4.3×10^4 OU h^{-1} m^{-2}). In addition, high airflow rates (table 1) and the unusually elevated H_2S concentrations at IA4B (most likely caused by high sulfur content in the drinking water) might have caused high odor emissions (Akdeniz et al., 2012).

Comparison of Barns and Species

Odor emissions (OU h^{-1} m^{-2}, OU h^{-1} head^{-1}, and OU h^{-1}

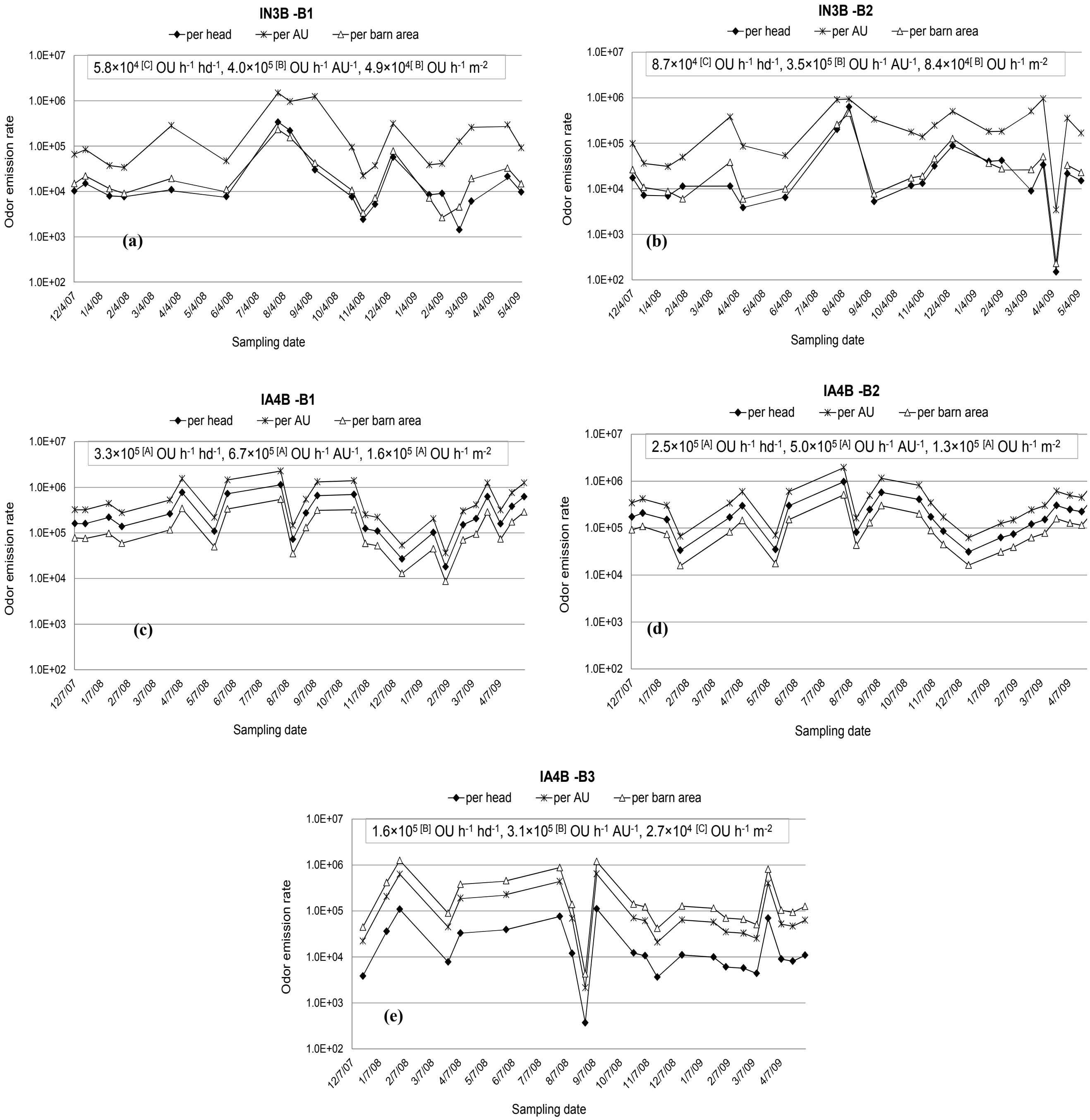

Figure 5. Average barn odor emission rates of sites IN3B (swine finishing) and IA4B (barns 1 and 2 were swine gestation barns, and barn 3 was a swine farrowing barn). Averages of three measurements are reported for IN3B and two measurements for IA4B for each sampling day (total of 25 sampling days per site). Overall average emission rate values (shown in boxes) followed by different letters are significantly different ($p < 0.05$). Emission rates in OU h^{-1} m^{-2}, OU h^{-1} $head^{-1}$, and OU h^{-1} AU^{-1} were evaluated separately. The *y*-axis is a log scale.

AU^{-1}) from two barns/rooms of a specific site generally showed similar trends (figs. 4 and 5). There was no significant difference between two barns/rooms of a site, except for the sow gestation barns (barns 1 and 2) and farrowing room (barn 3) at IA4B (figs. 5c, 5d, and 5e).

The odor emission rates from the farrowing room at IA4B were significantly lower than the odor emission rates of the sow gestation barns (tables 5 through 7). The farrowing room's emission rates in OU h^{-1} m^{-2} were also lowerthan the emission rates of the pig finishing rooms at IN3B. Jacobson et al. (2001), Gay et al. (2003), and Rahman and Newman (2012) found similar results. Lower emission rates per m^2 (OU h^{-1} m^{-2}) were reported for the farrowing barns compared to the sow gestation and pig finishing barns. On the other hand, when pig-specific emission rates were compared, emission rates of the farrowing room were significantly higher than those of finishing rooms. When live mass specific emission rates were compared, there was no significant difference between the emission rates of the farrowing and finishing rooms, while emission rates of the gestation barns were significantly higher.

The area-specific emission rates of the swine buildings were observed to be significantly higher than the emission rates of the dairy sites (tables 5 through 7, figs. 4 and 5). In addition, the hedonic tones of the swine sites were lower and odor intensities were higher than those of dairy sites (tables 8 and 9). The difference in odor emissions of the two species may have been due to long-term storage of manure in the swine barns. At the swine sites, in all barns except the farrowing room, manure was stored in deep pits underneath the barns. However, at the dairy sites, manure was removed every 8 h to outside storage basins. Many other factors, including diet composition and animal digestive system (ruminant versus non-ruminant), might have affected odor emission rates of the dairy and swine species (Janni, 2007).

Conclusions

Barn odor concentrations (OU m^{-3}) and emission rates (OU h^{-1} m^{-2}, OU h^{-1} $head^{-1}$, and OU h^{-1} AU^{-1}) showed seasonal patterns. The highest average airflow rates and emission rates and lowest barn odor concentrations were measured in summer, while the lowest average airflow rates and emission rates and highest barn odor concentrations were measured in winter.

Significant differences were observed in odor emission rates between sites. Odor emission rates of dairy site IN5B were significantly lower than those of dairy site WI5B. Site IN5B also had significantly lower odor intensities. Differences in odor emission rates of the dairy sites were most likely due to differences in manure management systems. It was observed that switching from a manure effluent flushing system to a tractor system caused significant reduction in odor emission rates at WI5B. Similar to the dairy sites, significant differences were observed in odor emission rates of the swine sites. Among all the barns assessed in this study, the highest odor emissions were measured from the sow gestation barns of site IA4B (1.4×10^5 OU h^{-1} m^{-2}, 2.9×10^5 OU h^{-1} $head^{-1}$, and 5.8×10^5 OU h^{-1} AU^{-1}). Therefore, using an odor control technology (e.g., gas-phase biofilters) is especially important for gestation barns in summer. When emission rates in OU h^{-1} $head^{-1}$ were compared, emission rates of the pig finishing rooms at IN3B were lower than the emission rates of the farrowing room at IA4B, but when emission rates in OU h^{-1} AU^{-1} were compared, there was no significant difference between the emission rates of the finishing and farrowing rooms.

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References

Akdeniz, N., L. D. Jacobson, B. P. Hetchler, S. D. Bereznicki, A. J. Heber, J. A. Koziel, L. Cai, S. Zhang, and D. B. Parker. 2012b. Odor and odorous chemical emissions from animal buildings: Part 4. Correlations between sensory and chemical measurements. *Trans. ASABE* 55(6): 2347-2356.

Aneja, V. P., W. H. Schlesinger, and J. W. Erisman. 2009. Effects of agriculture upon the air quality and climate: Research, policy, and regulations. *Environ. Sci.* 43(12): 4234-4240.

ASABE Standards. 2012. EP379.5: Management of manure odors. St. Joseph, Mich.: ASABE.

ASTM. 2001. E697-91: Standard practice for determining odor and taste thresholds by force-choice concentration series method of limits. Philadelphia, Pa.: ASTM.

Bereznicki, S. D., A. J. Heber, N. Akdeniz, L. D. Jacobson, B. P. Hetchler, K. Y. Heathcote, S. J. Hoff, J. A. Koziel, L. Cai, S. Zhang, D. B. Parker, E. A. Caraway, T. T. Lim, E. L. Cortus, and R. B. Jacko. 2012. Odor and odorous chemical emissions from animal buildings: Part 1. Project overview, collection methods, and quality control. *Trans. ASABE* 55(6): 2325-2334.

Blanes-Vidal, V., M. N. Hansen, A. P. S. Adamsen, A. Feilberg, S. O. Peterson, and B. B. Jensen. 2009. Characterization of odor released during handling of swine slurry: Part II. Effect of production type, storage, and physicochemical characteristics of the slurry. *Atmos. Environ.* 43(18): 3006-3014.

Bunton, B., P. O'Shaughnessy, S. Fitzsimmons, J. Gering, S. Hoff, M. Lyngbye, P. S. Thorne, J. Wasson, and M. Warner. 2007. Monitoring and modeling of emissions from concentrated animal feeding operations: Overview of methods. *Environ. Health Perspectives* 115(2): 303-307.

Cai, L., J. A. Koziel, S. Zhang, E. L. Cortus, D. B. Parker, S. J. Hoff, G. Sun, K. Y. Heathcote, L. D. Jacobson, N. Akdeniz, B. P. Hetchler, S. D. Bereznicki, A. J. Heber, E. A. Caraway, and T. T. Lim. 2012. Odor and odorous chemical emissions from animal buildings: Part 3. Chemical emissions. *Trans. ASABE* (in review).

Casey, K. D., J. R. Bicudo, D. R. Schmidt, A. Singh, S. W. Gay, R. S. Gates, L. D. Jacobson, and S. J. Hoff. 2006. Air quality and emissions from livestock and poultry production/waste management systems. In *Animal Agriculture and the Environment: National Center for Manure and Animal Waste Treatment White Papers*. J. M. Rice, D. F. Caldwell, and F. J. Humenik, eds. ASABE Publication No. 913C0306. St. Joseph, Mich.: ASABE.

CEN. 2003. EN13725:2003: Determination of odor concentration by dynamic olfactometry. Brussels, Belgium: European Committee for Standardization.

Gay, S. W., D. R. Schmidt, C. J. Clanton, K. A. Janni, L. D. Jacobson, and S. Weisberg. 2003. Odor, total reduced sulfur, and ammonia emissions from animal housing facilities and manure storage units in Minnesota. *Applied Eng. in Agric.* 19(3): 347-360.

Guo, H., W. Dehod, J. Agnew, C. Lague, J. R. Feddes, and S. Pang. 2006. Annual odor emission rate from different types of swine production buildings. *Trans. ASABE* 49(2): 517-525.

Guo, H., W. Dehod, J. Agnew, J. R. Feddes, C. Lague, and S. Pang. 2007. Daytime odor emission variations from various swine barns. *Trans. ASABE* 50(4): 1365-1372.

Guo, H., Y. Wang, and Y. Yuan. 2011. Annual variations of odor concentrations and emissions from swine gestation, farrowing, and nursery buildings. *J. Air Waste Mgmt. Assoc.* 61(12): 1361-1368.

Harssema, H. 1991. Field measurements of odorous air pollution with panels. In *Odour and Ammonia Emissions from Livestock Farming*, 203-211. V. C. Nielsen, J. H. Voorburg, and P.

L'Hermite, eds. New York, N.Y.: Elsevier Applied Science.
Hoff, S. J., D. S. Bundy, M. A. Nelson, B. C. Zelle, L. D. Jacobson, A. J. Heber, J. Ni, Y. Zhang, J. A. Koziel, and D. B. Beasley. 2006. Emissions of ammonia, hydrogen sulfide, and odor before, during, and after slurry removal from a deep-pit swine finisher. *J. Air Waste Mgmt. Assoc.* 56(5): 581-590.
IUPAC. 2012. *Compendium of Chemical Terminology Gold Book*, V.2.3.1. 2012-03-23. Research Triangle Park, N.C.: International Union of Pure and Applied Chemistry. Available at: http://goldbook.iupac.org/PDF/goldbook.pdf. Accessed 22 May 2012.
Jacobson, L. D., S. L. Wood, D. R. Schmidt, A. J. Heber, J. R. Bicudo, and R. D. Moon. 2001. Site selection of animal feeding operations using air quality criteria. In *Proc. Intl. Symp. Addressing Animal Production and Environmental Issues*. Raleigh, N.C.: North Carolina State University.
Jacobson, L. D., B. P. Hetchler, D. R. Schmidt, R. E. Nicolai, A. J. Heber, J. Q. Ni, S. J. Hoff, J. A. Koziel, Y. Zhang, D. B. Beasley, and D. B. Parker. 2008. Quality assured measurements of animal building emissions: Odor concentrations. *J Air Waste Mgmt. Assoc.* 58(6): 806-811.
Janni, K. A. 2007. Evaluation of air quality implications of proposed manure management technologies. Available at: www.fppcinc.org/airquality/Air_Quality_Implication.doc. Accessed 1 January 2012.
Jin, Y., T. T. Lim, J. Q. Ni, J.-H. Ha, and A. J. Heber. 2012. Emissions monitoring at a deep-pit swine finishing facility: Research methods and system performance. *J Air Waste Mgmt. Assoc*. (in press, doi: 10.1080/10962247.2012.707163).
Lee, J., and Y. Zhang. 2008. Evaluation of gas emissions from animal building dusts using a cylindrical convective chamber. *Biosyst. Eng.* 99(3): 403-411.
Misselbrook, T. H., and J. M. Powell. 2005. Influence of bedding material on ammonia emissions from cattle excreta. *J. Dairy Sci.* 88(12): 4304-4312.
Ni, J. Q., A. J. Heber, M. J. Darr, T. T. Lim, C. A. Diehl, and B. W. Bogan. 2009. Air quality monitoring and on-site computer system for livestock and poultry environment studies. *Trans. ASABE* 52(3): 937-947.
Nicell, J. A. 2009. Assessment and regulation of odor impacts. *Atmos. Environ.* 43(1): 196-206.
Oehlert, G. 2000. *A First Course in Design and Analysis of Experiments*. Minneapolis, Minn.: University of Minnesota. Available at: http://users.stat.umn.edu/~gary/book/fcdae.pdf. Accessed 6 February 2012.
Parker, D. B. 2008. Reduction of odor and VOC emissions from a dairy lagoon. *Applied Eng. in Agric.* 24(5): 647-655.
Parker, D. B. 2010. Effectiveness of a manure scraper system for odor control in tunnel-ventilated swine finisher barns. *Trans. ASABE* 53(1): 315-324.
Parker, D. B., M. B. Rhoades, G. L. Schuster, J. A. Koziel, and Z. L. Perschbacher-Buser. 2005. Odor characterization at open-lot beef cattle feedyards using triangular forced-choice olfactometry. *Trans. ASAE* 48(4): 1527-1535.
Parker, D. B., J. A. Koziel, L. Cai, L. D. Jacobson, N. Akdeniz, S. D. Bereznicki, T. T. Lim, E. A. Caraway, S. Zhang, S. J. Hoff, A. J. Heber, K. Y. Heathcote, and B. P. Hetchler. 2012. Odor and odorous chemical emissions from animal buildings: Part 6. Odor activity value. *Trans. ASABE* 55(6): 2357-2368.
Rahman, S., and D. Newman. 2012. Odor, ammonia, and hydrogen sulfide concentration and emissions from two farrowing-gestation swine operations in North Dakota. *Applied Eng. in Agric.* 28(1): 107-115.
Qu, G., I. E. Edeogu, and J. J. R. Feddes. 2010. Odor index: An integration of odor parameters for swine slurry odors. *Trans. ASABE* 53(1): 219-223.
Schauberger, G., T. T. Lim, J. Q. Ni, D. S. Bundy, B. L. Haymore, C. A. Diehl, R. K. Duggirala, and A. J. Heber. 2012. Empirical model of odor emission from deep-pit swine finishing barns to derive a standardized odor emission factor. *Atmos. Environ.* (in press, doi: 10.1016/j.atmosenv.2012.05.046).
Sheffield, R. E., M. Chahine, B. Dye, and M. B. Thompson. 2007. Odor concentrations downwind of Idaho dairies and heifer facilities. *Trans. ASABE* 50(1): 255-263.
Sun, G., H. Guo, and J. Peterson. 2010. Seasonal odor, ammonia, hydrogen sulfide, and carbon dioxide concentrations and emissions from swine grower-finisher rooms. *J. Air Waste Mgmt. Assoc.* 60(4): 471-480.
VDI. 1992. VDI Guideline 3882 Bl. 2: Olfactometry; Determination of hedonic odour tone. Düsseldorf, Germany: VDI Verlag.
Yu, Z., H. Guo, and C. Lague. 2010. Livestock odor dispersion modeling: A review. *Trans. ASABE* 53(4): 1231-1244.
Zhang, S., L. Cai, J. A. Koziel, S. J. Hoff, K. Y. Heathcote, L. Chen, L. D. Jacobson, N. Akdeniz, B. P. Hetchler, D. B. Parker, E. A. Caraway, A. J. Heber, and S. D. Bereznicki. 2012. Odor and odorous chemical emissions from animal buildings: Part 5. Correlations between odor intensities and chemical concentrations (GC-MS-O). *Trans. ASABE* (in review).
Zhao, L. Y., M. F. Brugger, R. B. Manuzon, G. Arnold, and E. Imerman. 2007. Variations in air quality of new Ohio dairy facilities with natural ventilation systems. *Applied Eng. in Agric.* 23(3): 339-346.